MASTER WEB INTELLIGENCE

Multi-Agent Systems

Introduction

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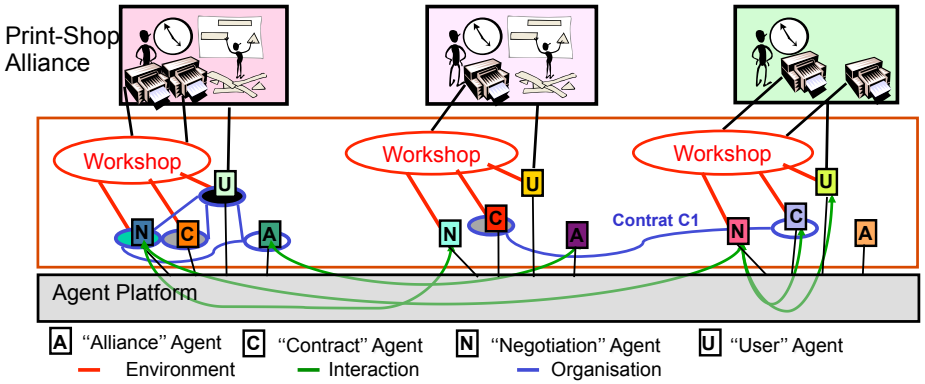
Plan

1. **Definitions**
2. Action Domains
3. Positioning
4. Multi-Agent Engineering
5. Perspectives …

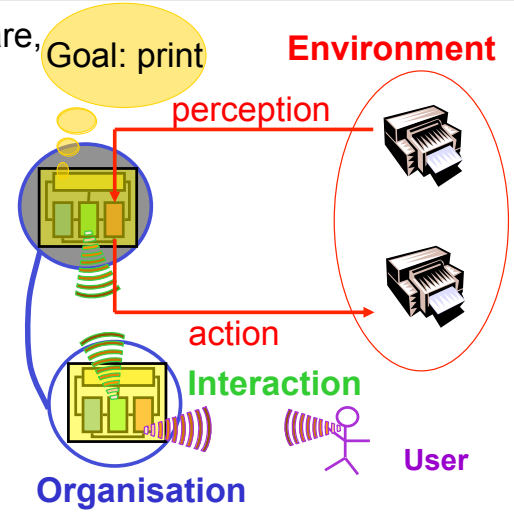
Multi-Agent Systems



Multi-Agent System (MAS) : set of agents, that interact with each other, situated in a common environment, eventually, building or participating to, an organisation

Agent (in a Multi-Agent World)

Agent : physical or software, *autonomous* entity that is pro-active, reactive, social, able to take part to an organised activity, in order to achieve its goals, by interacting with other agents and users.



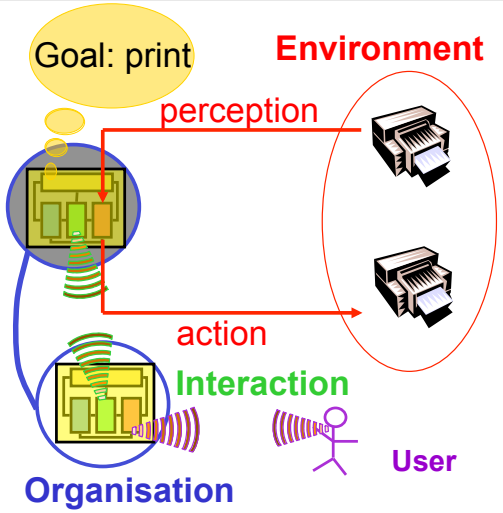
Autonomous Agent (in a Multi-Agent World)

- An agent ***X*** is autonomous with respect to ***Y*** for ***O*** in situation ***S***
  - ***Y*** can be a user, another agent, a group of agents, an organisation, …
  - ***O*** can be a *goal*, a *plan*, an *action*, a *resource*, a *norm*, a *role*, …

It means that:

- agent ***X*** can *decide locally* of the adoption of ***O*** in situation ***S***
- **And** ***Y*** *has no certainty that* ***X*** is going to adopt ***O*** in situation ***S***

→ **Loose** coupling between agents



Multi-Agent Systems Principles

- The ***Agent perspective*** (micro perspective)
  - *Reactive* & *Pro-Active* entities
  - *Autonomy*: agents may exhibit activities that are not the one expected by the other agents in the system
  - *Delegation*: agents may receive some control over their activities
- The ***Multi-Agent System perspective*** (macro perspective)
  - *Distribution* of knowledge, of resources, of reasoning/decision capabilities
  - *Decentralization* (loose coupling) of control, authority
  - Agreement technologies, Coordination models and mechanisms to install coordination between the autonomous agents
  - Emergent / Social order / Normative functioning

Plan

MAS Action domains

- **Socio-technical Systems**
  - Integration of software applications, with humans, organizations and the physical world
  - Making them interoperate, interact, cooperate in a flexible and consistent manner with each other
- **Problem Solving**
  - Modeling and solving problems by cooperation between local solvers
  - Installing top-down and/or bottom-up (emergent) solving process
- **Simulation**
  - Modeling and reproducing complex phenomena of interacting entities in the real world in order to understand or to explain their behavior

Socio-Technical Systems (1)

- Industries, services, IT applications are getting global
  - Placed at the centre of multiple networks
  - Developing Knowledge intensive processes
  - Based on large scale underlying IT platforms such as Internet, Web, Internet of Things
- Industries, services, IT applications are situated in an ever-evolving environment
  - Requiring efficient collaboration processes
  - While keeping flexibility and agility
- Users are more and more at the centre of the cooperation and collaboration taking place in these socio-technical systems

Socio-Technical Systems (2)

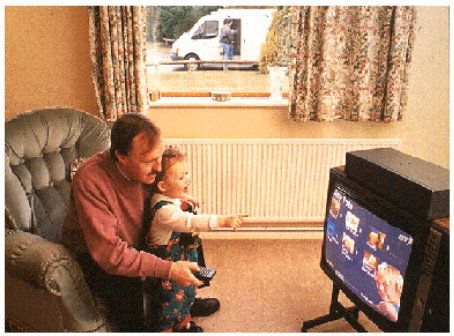
- Properties of the targeted applications:
  - Absence of monolithic vision
  - Incremental development, by different teams
  - Multi-* (sites, expertise, domains, points of view, decisions, goals, motivations, …)
  - Continuous execution and adaptation
  - User-Centred
- Main requirements:
  - Openness, permeability, scalability in size or structure
  - Distribution, no central control, control and interaction are local
  - Autonomous Interacting entities loosely coupled with others or applications
  - Knowledge Intensive processing and sharing
  - Users may delegate their decisions to the application

Example (1/3)

Service Personnalisation

Tonight's Suggested Viewing:

7pm World News Headlines
7:15 Personal Newsround
7:30 Selected highlights of today's golf
7:50-8:00 Intermission (Video-call - it's your brother's birthday)
8:00-10:00 Film choice
Jurassic Park (VR) OR Cyberspace 2
(please select now)



Source CLIMATE Industrial Workshop 26/4/99

Example (1/3)

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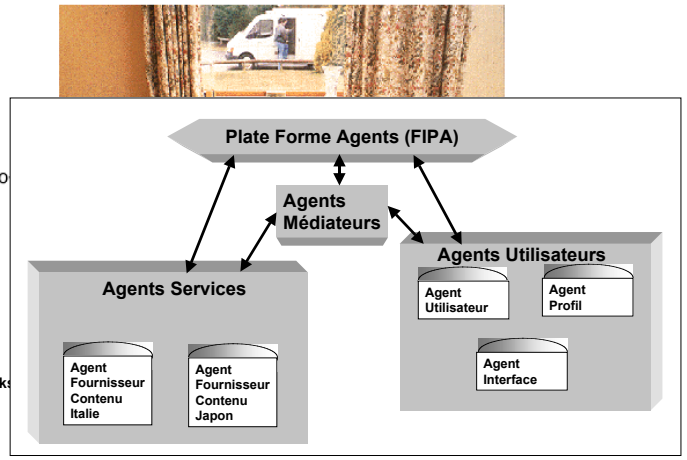
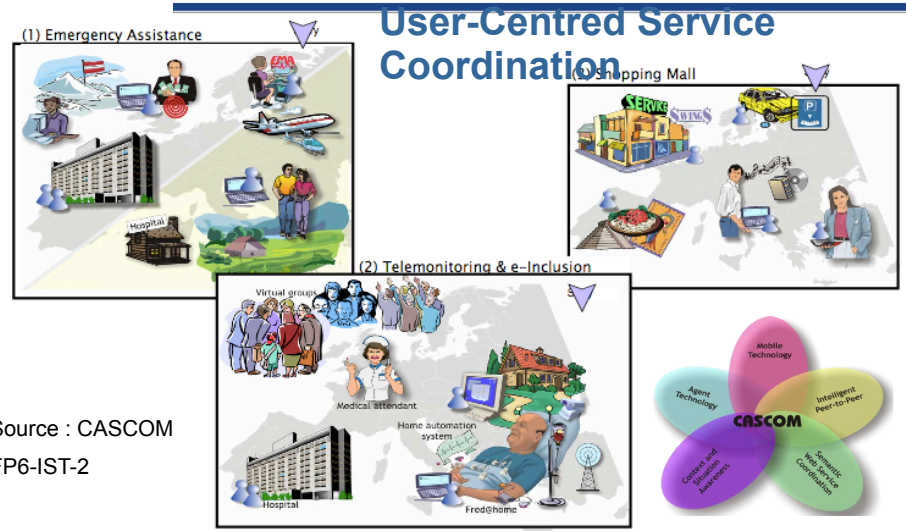
Source CLIMATE Industrial Works



Example (2/3)

User-Centred Service Coordination



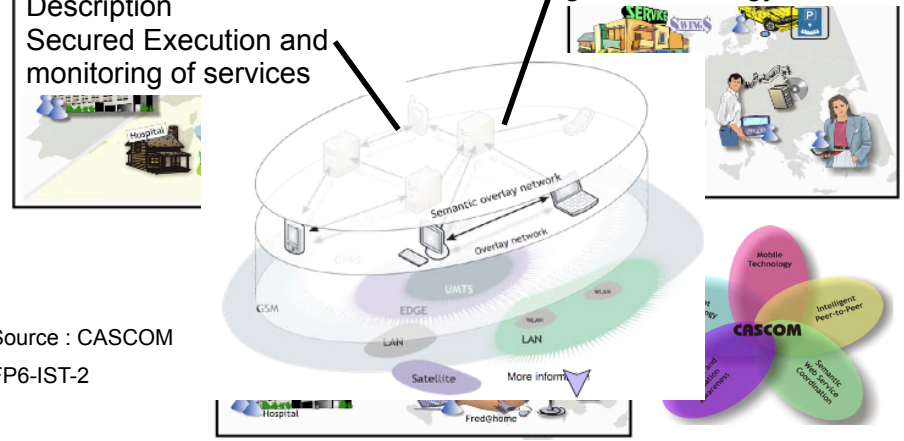
Source : CASCOM

FP6-IST-2

Example (2/3)

Service Composition
Semantic Services Description
Secured Execution and monitoring of services

Semantic Web
Agent Technology

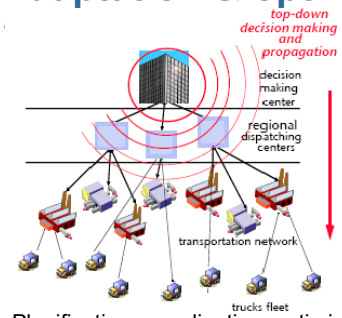


Source : CASCOM

FP6-IST-2

Example (3/3)

Adaptation & optimisation



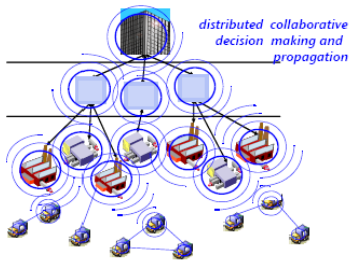
Planification, coordination, optimisation along a top-down approach *:*

- *Centralised collect and processing of informations and events*
- Propagation of plans & decisions
- No realtime decision.

Source Whitestein Agent Technology Conference 2004

Planification, coordination, optimisation along a bottom-up approach

- Responsibility Delegation
- Communication between the nodes
- Real time detection & reaction to changes
- Adaptation to changes & continuous optimisation



MAS Action domains

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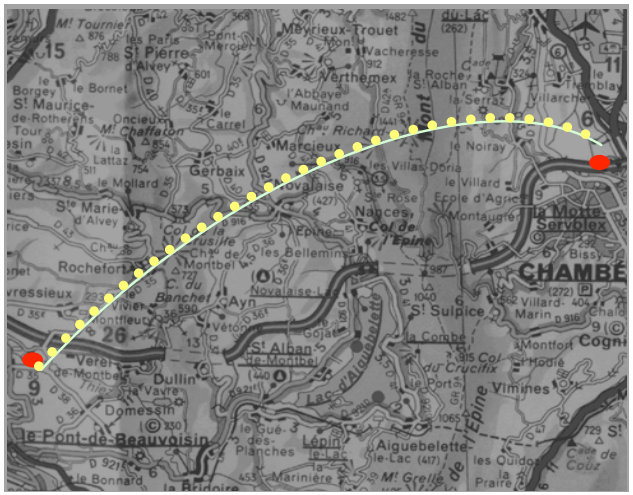
  - Modeling and reproducing complex phenomena of interacting entities in the real world in order to understand or to explain their behavior

Problem Solving

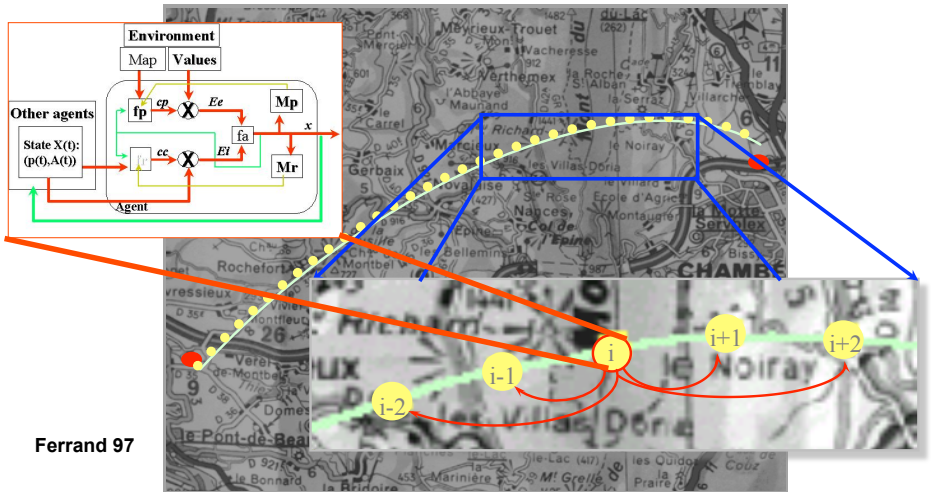
- Properties of the targeted applications:
  - Absence of global strategies, of global solving method
  - Interaction between local strategies, between local solving methods
  - Solution is the result of the interaction between local processes (points of view, decisions, goals, motivations, …)
  - Continuous functioning and evolution
- Main requirements:
  - Decentralisation, local control, interactions
  - Openness, permeability, scalability in size or structure
  - Shared and dynamic environment
  - Emergence of the solution

Example (1/2)



Ferrand 97

Example (1/2)

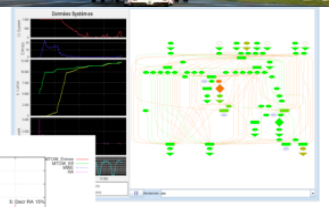


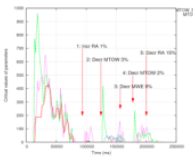
Ferrand 97

Example (2/2)

Design of Complex Systems

- Multi-Disciplinary Simulation & optimisation (ID4CS)
- Design of complex system :
  - Multi-level, Multi-disciplinary
  - Multi-methods
  - Multi-objectives, Multi-attributes
  - Uncertainty
- Cooperation methods between optimisation technics,
- Management of uncertainty
- Multi-* problem solving
- Emergence





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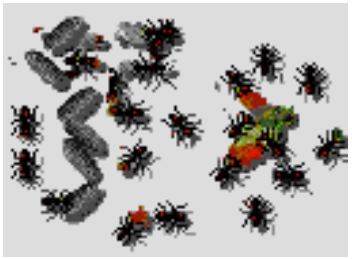
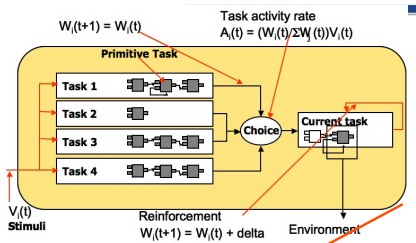
Example (1/2)

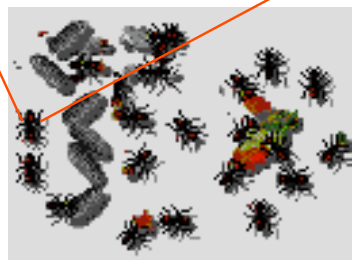
In order to:

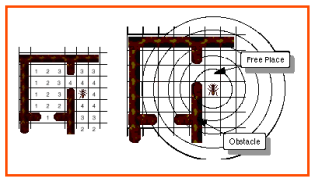


Understand, Explain
Discover, …, Help,

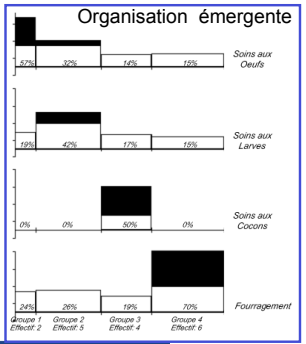
Example (1/2)







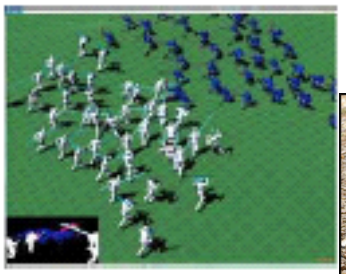
MANTA [Drogoul 93]



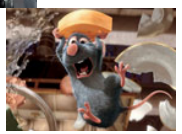
Example (2/2)

http://www.massivesoftware.com/

The Return of the King (2003)
The Two Towers (2002)
The Fellowship of the Ring (2001)



I, Robot (2004)



Ratatouille (2007)

…, Entertainment

Conversational Zeno Robot
http://hansonrobotics.com/

Plan

1. Contexte
2. Definitions
3. Action Domains
4. **Positioning**
5. Multi-Agent Engineering
6. Perspectives …

History – Major Steps

- 1980 : Agents in the Artificial Intelligence (AI) area
  - From AI to **Distributed** AI …

  … to Multi-Agent Systems
- 1990 : Agents are invading other domains
  - Personal Assistants, avatars,
  - Mobile Agents,
  - Reactive Agents, ….
- 1995 : Agents spread in other domains, Application domains are enlarging
  - Artificial Life, Economic Agents, …,
  - …, Web, Ambient Computing, …

History – Evolutions

- 1973 - 1980:
  - Hearsay II (1973): blackboard architecture for speech recognition
  - Actor Languages (1973): messages as control structures
  - Beings (1975), Society of Minds (1978)
- 1980 - 1990:
  - Contract Net (1980): hierarchical decentralized control
  - DVMT (1984): Distributed Interpretation
  - Subsumption architecture (1986) : Reactive Robots
  - MACE (1987): multi-agent platforms
- 1990 - … :
  - Self-organisation, emergence, Interactions, organisations, reputation, trust, Agent Oriented Software Engineering, …
  - In 1995, first international conference ICMAS,
  - since 2002, Autonomous Agents + MAS -> AAMAS

Inter-Disciplinary Domain…

- Direct Links with:
  - Programming, Objects...
  - Artificial Intelligence,
  - Distributed Systems, Parallelism,
- But also:
  - Complex System (physics, …, ethology, ecology, …)
  - Artificial Life, Neural networks, …
  - Social Psychology, Sociology, Activity Theory, Economy, ...

Direct Inheritance

- Object Oriented Programming:
  - Encapsulation, modularity : an object encapsulate data and methods that manage them (ex : C++, Java, Smalltalk),
  - Distribution : Distributed objects, CORBA, DCOM
  - → Actor Languages Development
- Artificial Intelligence:
  - Symbolic Reasoning Models (Expert systems, Knowledge Representation), logic, …
  - distribution : Blackboard Architectures
- Distributed Systems

Multi-Agent vs Objects

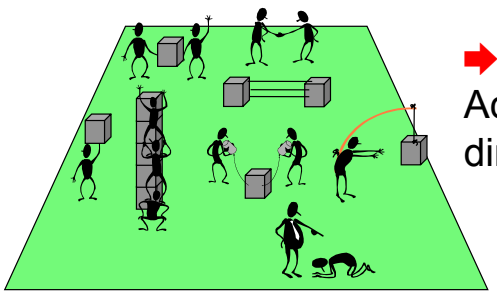
- An agent, as an object, encapsulate a state and behaviors

BUT:

- An agent encapsulate its control over its behaviors; an object has only control over its state
- Interactions among agents have a broader scope than the method calls between objects. Interactions consist in goals, plans, actions, hypothesis exchanges
- An agent may have different control cycles (data-directed, goal-directed, interaction-directed, …)
- A MAS has several control flows. An Object system has, a priori, only one control flow.

Multi-Agent vs Artificial Intelligence (1)

Mono-agent of Artificial Intelligence is rejected



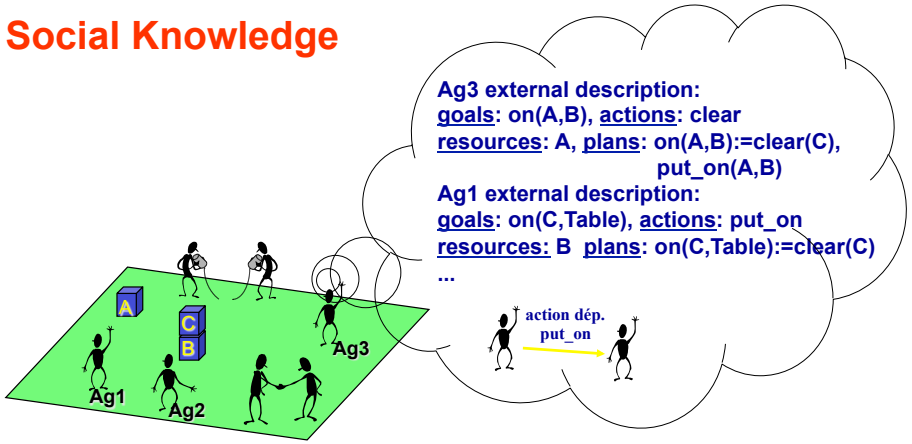
➡ Knowledge, Goals, Actions gain a **social** dimension

Multi-Agent vs Artificial Intelligence (2)

Ex. dependence networks

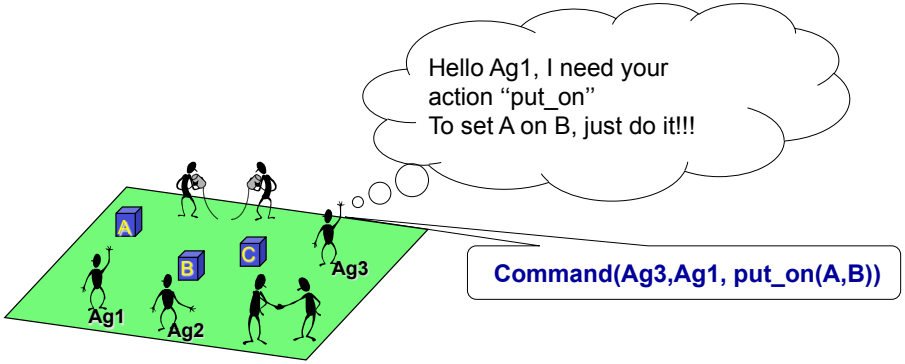
Multi-Agent vs Artificial Intelligence (3)

Social Knowledge



Multi-Agent vs Artificial Intelligence (4)

Social Interaction



Multi-Agent vs Distributed Systems

- Both take into account interconnection and distribution
- In MAS, Interconnection and Distribution are concerned by:
  - The requirement of taking into account the agent autonomy, of developing synchronization and coordination mechanisms to coordinate their activities
  - The requirement to represent and take into account the user interests
  - The requirement to cooperate and to achieve agreements (or even compete) with other systems aiming at achieving their own interests.

A Large Domain!!!

From *Autonomous Agents* to *Multi-Agent Systems*

- Autonomous Robots
- Personal Assistants
- Desktop Agents
- Softbots, Knowbots
- Mobile Agents
- Reactive Agents
- Intelligent Agents, Cooperative Agents, Conversational Agents
- Autonomous Agent in a multi-agent world

Plan

1. Definitions
2. Action Domains
3. Positioning
4. **Multi-Agent Engineering**
5. Perspectives …

Multi-Agent Engineering

- Developing multi-agent applications is often a difficult task
  - implementation, distribution, communications, …
- There exists
  - Multiple technologies focused on particular points of a MAS
  - Multiple agent programming languages, dedicated or general purpose based on existing programming languages
  - Multiple multi-agent programming platforms, involving often a specific agent architecture, proposing or not, first order abstractions for the environment, the organisation, the interaction.
  - Multiple standards
  - Multiple software engineering methods for the analysis and design of MAS.

→ Multiple languages, platforms, methods are available …

→ But often limited to a very focused set of applicative domains.

→ Which one to choose? How to choose? How to compare?

Multi-Agent Technologies

Technologies

- Agent Architectures and Theories
- Coalition formation mechanisms
- Multi-Agent Planning
- Agent Communication Languages, Interaction Protocols
- Auction mechanisms
- Negotiation strategies and mechanisms, Argumentation
- Electronic Institutions, Organisations, Norms
- Reputation, Trust
- Mono & multi-agent Learning
- Self-organisation, emergence, …

Declarative Approach

Languages

- CLAIM (Computational Language for Autonomous Intelligent and Mobile Agents)
  - Cognitive Agent Programming Language
  - Belonging to Himalaya Framework (Hierarchical Intelligent Mobile Agents for building Large-scale and Adaptive sYstems based on Ambients)
  - Based on process algebra in order to represent concurrency and agent mobility
  - Based on SyMPA platform implemented in JAVA respecting the MASIF standard
- FLUX :
  - Cognitive Agent Programming Language
  - Fluent Calculus implementation (Action representation formalism)
  - http://www.fluxagent.org

Imperative Approach

- JACK Agent Language (JAL)
  - Developed by Agent Oriented Software
  - Based on PRS, BDI model (similar to hybrid languages such as Jason, 3APL, Jadex)
  - JAL is an extension of Java allowing to create plans, beliefs base, …
  - Possibility to use team of agents, organisation of agents
  - http://www.agent-software.com

Hybrid Approach

- 3APL (An Abstract Agent Programming Language « triple-a-p-l »)
  - Programming language for the development of cognitive agents:
    - By defining structures for beliefs, goals, plans, actions (internal, external or communication) and reasoning rules (modification of plan bases),
    - By reasoning methods to generate plans, revise plans, to achieve goals
    - Integration of Prolog and Java
    - http://www.cs.uu.nl/3apl
- Jason : extended version of AgentSpeak(L) interpreter, agent oriented programming language based on logic. Introduced by Rao.

  - Communication between agents based on Speech-act (beliefs and goals annotated by the information sources)
  - Plans annotations
  - Functions for selecting, for trust computation,
  - Functions and agent architecture may be adapted (perception, belief-revision, inter-agent communication, acting)
  - Integration by the user of existing code by the way of internal
  - Implemented in java, bound to the organisational language MOISE, interfaced with the CARTAGO platform
  - http://jason.sourceforge.net

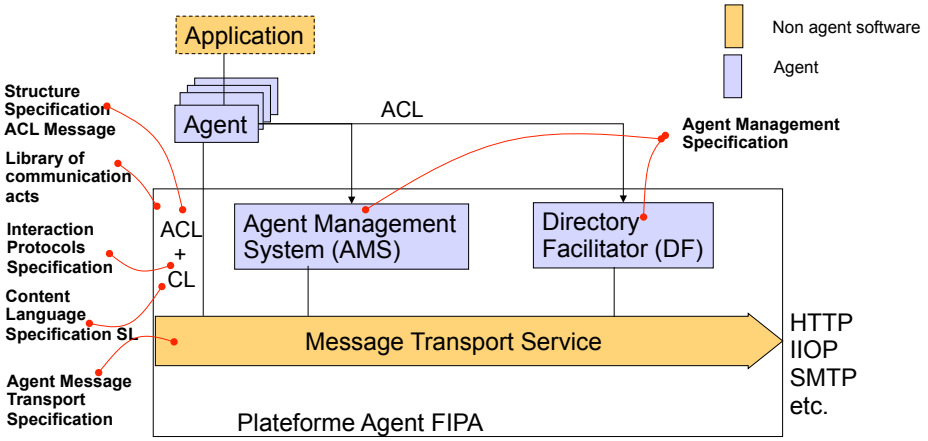
Existing Platforms

- Platforms
  - FIPA compliant
    - FIPA-OS (http://sourceforge.net/projects/fipa-os/)
    - Jade/LEAP (http://jade.tilab.com/)
  - Others :
    - SACI Simple Agent Communication Infrastructure (http://www.lti.pcs.usp.br/saci/)
- Developping Environments
  - Madkit (www.madkit.org)
  - JADEX, BDI agent model based on JADE (http://sourceforge.net/projects/jadex)
  - JACK execution environment, compiler, BDI agent model based on Procedural Reasoning System (PRS) (http://www.agent-software.com)
  - AgentBuilder based on Agent Oriented Program (AOP) (http://www.agentbuilder.com/)
  - AgentTool (http://macr.cis.ksu.edu/projects/agentTool/agentool.htm)
  - ADELFE (http://www.irit.fr/ADELFE/)
- Have a look at *Software Products for MAS*, AgentLink, June 2002

Standards

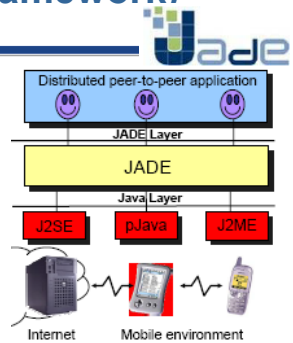
- **Knowledge Sharing Effort** The DARPA Knowledge Sharing Effort
  - http://www-ksl.stanford.edu/knowledge-sharing/
- **MASIF** - OMG (Object Management Group) : OMG effort to standardize mobile agents - middleware services and internal middleware interfaces
  - www.omg.org
- IEEE Computer Society FIPA Standards Committee (**Foundation for Intelligent Physical Agents**)
  - www.fipa.org

FIPA Plateform



ACL = Agent Communication Language

JADE (Java Agent DEvelopment Framework)



- Middleware for developing agent-based P2P application
  - On fixed platforms, smart phones, …
- Two main products :
  - Agent Platform compliant to FIPA specifications
  - API to develop agents in Java
- Open Source Project, LGPL License
- Controlled by Telecom Italia Lab, who owns the project
- Result of the joint effort of multiple actors belonging to the JADE Board (founded in 2003) which missions concern the promotion, the governance and implementation of the changes of the JADE platform

MOTOROLA WHITESTEIN Technologies TELECOM LAB PROFACTOR

- Project portal : http://jade.tilab.com

Standards & Multi-Agent Systems

- Ontologies : DAML, OIL, OWL, …
  - http://www.daml.org
  - http://www.ontoknowledge.org/oil/
  - http://www.w3.org/
- Other standards (De Facto)
  - Jini (www.sun.com/jini),
  - UPnP (www.upnp.org),
  - UDDI (www.uddi.org),
  - Salutation (www.salutation.org)
  - mobility : Aglets (www.trl.ibm.com/aglets/)
  - Web Services (http://www.w3.org/)
  - …

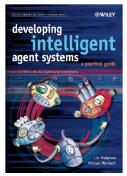
Multi-Agent Methodologies

The engineering of Multi-Agent Systems needs to take into account two levels:

- Multi-Agent System level (System-Centred)
  - Number of agents, Agent Heterogeneity?
  - What is the common medium shared by the agents (Environment)?
  - What are the communication mechanisms between agents?
  - What are the communication languages, the ontologies, the interaction protocols used by the agents?
  - What is the organisation regulating the actions of the agents? How is it established?
  - How do the agents coordinate their actions? How to ensure a consistent behavior?
- Agent level (Agent-Centred)
  - What does an agent represent? What are the kinds of actions encapsulated into an agent?
  - How do the agents represent the environment, the organisation in which they are situated?
  - How do the agents process the interaction with other agents?
  - What is the agent architecture?

Tools supporting methods

- Software Engineering Tools supporting methodologies:
  - MASE AgentTool : macr.cis.ksu.edu/projects/agentTool/agentool.htm
  - ZEUS : sourceforge.net/projects/zeusagent
  - Prometheus PDT : http://www.cs.rmit.edu.au/agents/pdt/
  - PASSI ToolKit : mozart.csai.unipa.it/passi/ptk.htm
  - INGENIAS : grasia.fdi.ucm.es/ingenias/
  - OPM : www.objectprocess.org
- Different ways to model applications:
  - *Agent* Oriented Software Engineering
  - *Environment* Oriented Software Engineering
  - *Interaction* Oriented Software Engineering
  - *Organization* Oriented Software Engineering



Plan

1. Definitions
2. Action Domains
3. Positioning
4. Multi-Agent Engineering
5. **Perspectives …**

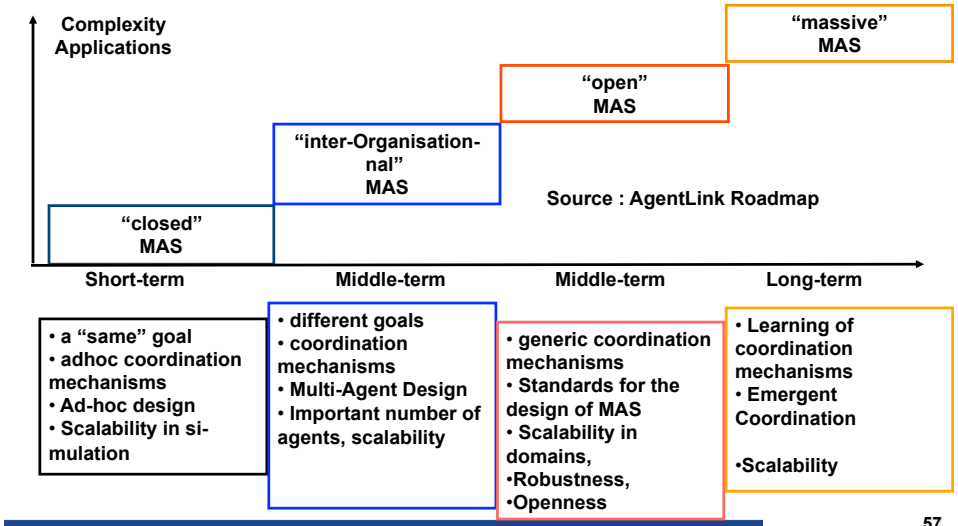
To continue …

- General references
  - Pitfalls of Agent-Oriented Development, M. Wooldridge, N.R. Jennings, Agents '98, 1998.
  - Foundations of Distributed Artificial Intelligence, G.M.P. Hoare, N.R. Jennings, Wiley & Sons, 1996
  - Les systèmes multi-agents, J. Ferber, InterEditions, 1995
  - Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence, edited by Gerhard Weiss, MIT Press, 1999. ISBN 0-262-23203-0
  - Principes et architectures des Systèmes Multi-Agents, J.P. Briot, Y. Demazeau, IC2, Hermès, 2001
- Some standards
  - Knowledge Sharing Effort http://www.cs.umbc.edu/kse/
  - OMG Agent Working Group http://www.objs.com/isig/agent.html
  - FIPA http://www.fipa.org
  - W3C http://www.w3.org
- Some general adresses
  - Collège SMA de l'AFIA : http://sma.lip6.fr
  - AgentLink : http://www.agentlink.org
  - AgentCities : http://www.agentcities.org

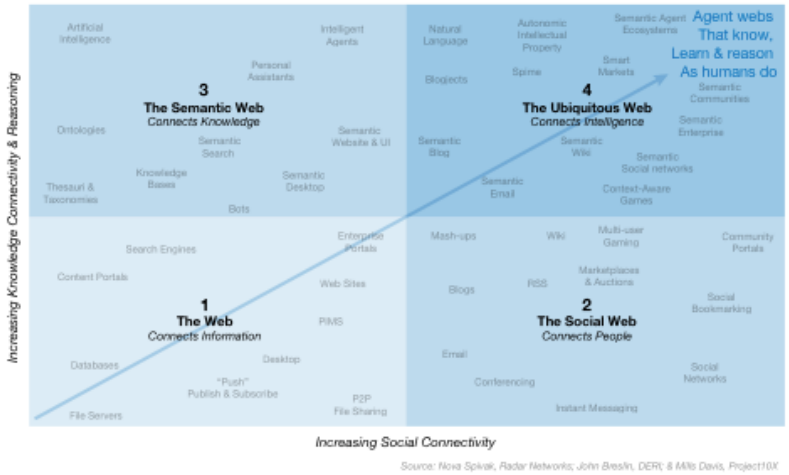
Multi-Agent Modeling

- Multi-model :
  - Articulation of different formalisms
- Multi-viewpoints :
  - Extern/intern, system centred/agent centred
  - Multiple views on a shared world
- Multi-levels
  - Via organisations, via the environment (MAS)
- Multi-scales
  - temporal, spatial, …

Scientific Challenges



Applicative Challenges



Domain Overview (1/2)

- International Conferences
  - International Conference on Multi-Agent System (ICMAS) de 1995 à 2000,
  - International Conference on Autonomous Agents and MultiAgent Systems (AAMAS) depuis 2002. (http://www.aamas-conference.org/)
- French Conferences
  - Journées Francophones SMA (http://www.cerv.fr/jfsma08/)
  - Collège SMA de l'AFIA (http://sma.lip6.fr/)
- European Projects
  - AgentLink (réseau d'excellence www.agentlink.org), Roadmap (www.agentlink.org/roadmap)
- Some ''Success Stories''
  - Brahms (agentsolutions http://agentsolutions.com/home.htm) @ NASA Ames Research Center
  - Living Systems (Whitestein technologies http://www.whitestein.com) @ ABX Logistics
  - eSTAR (http://www.estar.org.uk/) intelligent robotic telescope network
  - CalicoJack (http://www.calicojack.co.uk/)
  - Review of Industrial Deployment of Multi-Agent Systems http://agents.felk.cvut.cz/teaching/33ui2/on-aplications.pdf

Domain Overview (2/2)

- Standards
  - FIPA (Foundation for Intelligent Physical Agents) (http://www.fipa.org/)
- Competitions

http://www.robocup.org/

http://www.rescuesystem.org/robocuprescue/

Trading Agent Competition TAC

http://tac.eecs.umich.edu/association.html

http://www.lips.utexas.edu/art-testbed/

Domain Overview (3/3)

- Journals
  - Autonomous Agents and Multi-Agent Systems
  - Artificial Intelligence
  - Knowledge Engineering Review
  - International Journal of Agent-Oriented Software Engineering (IJAOSE)
  - Web Intelligence and Agent Systems *An International Journal*
- News
  - Agent List
    - http://www.cs.umbc.edu/agentslist/
  - Distributed Artificial Intelligence List
    - DAI-List-Request@ece.sc.edu
  - French list
    - sma@loria.fr
    - http://sma.lip6.fr/

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